



## Variable Vector Countermeasure Suit (V2Suit) for Space Habitation and Exploration

### NASA Innovative Advanced Concepts Phase 1

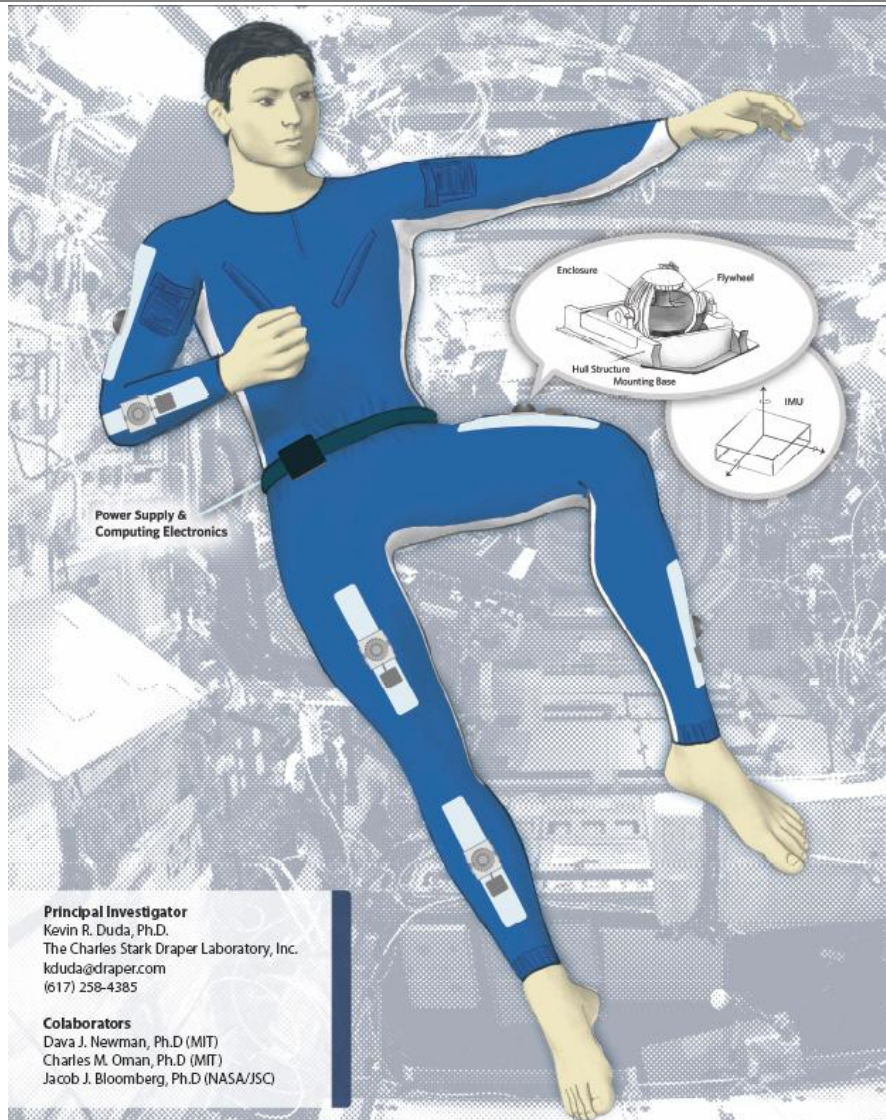
Kevin R. Duda, Ph.D.

The Charles Stark Draper Laboratory, Inc.

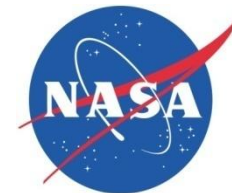
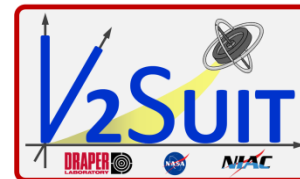
NIAC Spring Symposium  
March 27-29, 2012  
Pasadena, CA



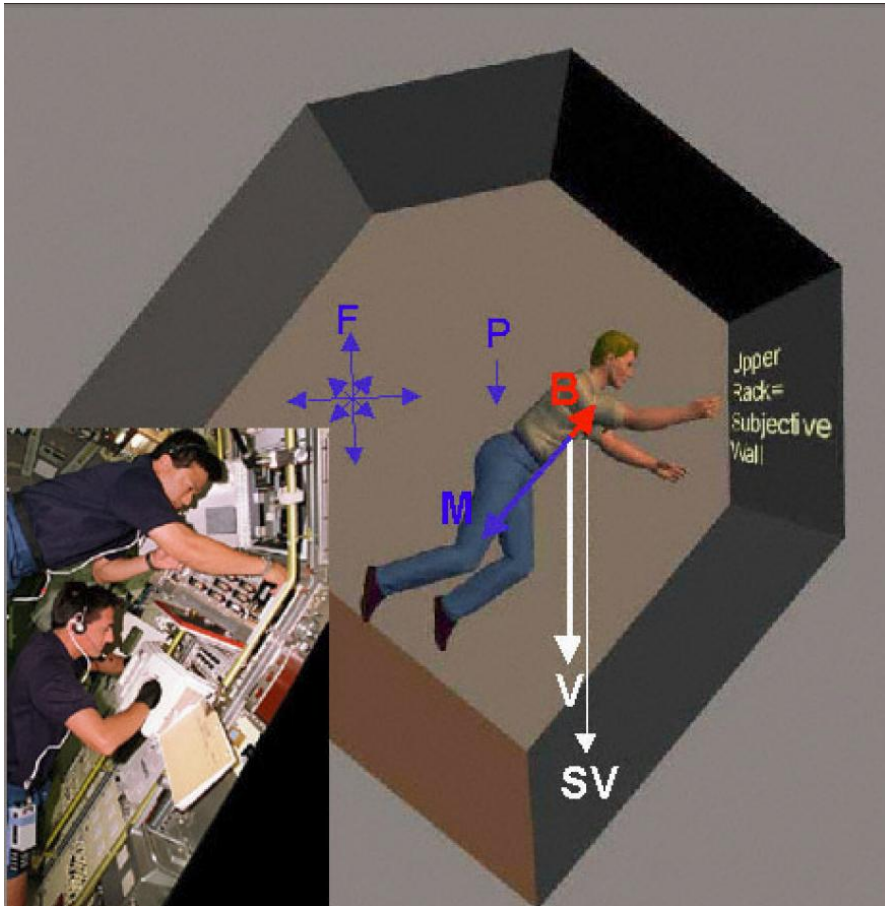
# V2Suit for Space Habitation and Exploration



- **Spaceflight adaptation countermeasure suit**
  - Sensorimotor
  - Musculoskeletal
- Utilizes properties of gyroscopes to provide “viscous resistance” during movement



# V2Suit Motivation



- No “down” in 0-G
  - Visual perceptions dominate
  - “Down” direction may change
- Physiological adaptation to weightlessness
- Perceptual and resistance benefits:
  - Sensorimotor adaptation
    - Earth G, Moon G, Mars G
    - Full-body, tactile perception
  - Musculoskeletal de-conditioning

The V2Suit facilitates human adaptation and performance during long-duration spaceflight

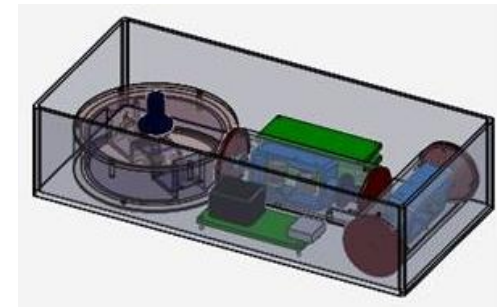
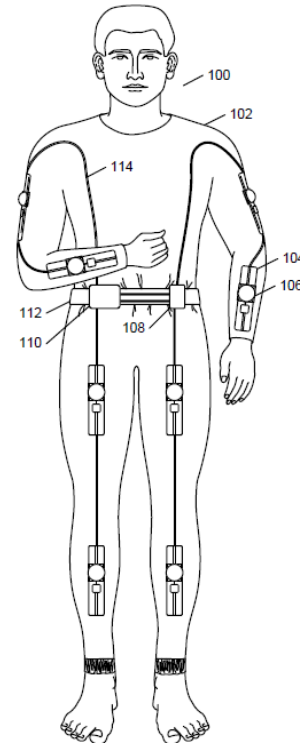
Oman, Charles M., Chapter 19: Human Visual Orientation in Weightlessness, in *Levels of Perception*, L.R. Harris and M. Jenkin, Editors. 2003, Springer-Verlag: New York. p. 375-395.

Bloomberg, J. *Promoting Sensorimotor Response Generalizability: A Countermeasure to Mitigate Locomotor Dysfunction After Long-Duration Space Flight (Mobility)*. 2006 ; Available from: <http://exploration.nasa.gov/programs/station/Mobility.html>.



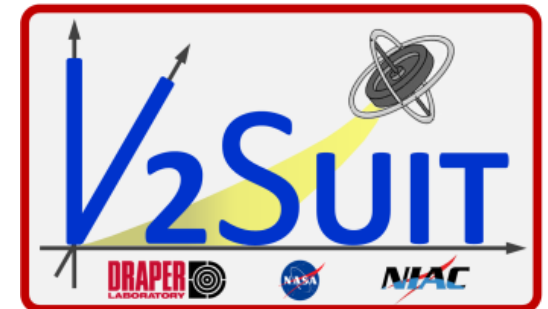
# V2Suit Phase 1 Progress

- **U.S. Patent Application**
  - “Exoskeleton Suit for Adaptive Resistance to Movement”
  - Submitted: November 30, 2011
- **Media Coverage**
  - The Washington Post, txchnologist.com, \., Space.com, Space-travel.com, plus others
- **Human-System Integration**
  - Form factor concept
  - Module placement
  - Interface with body/garment
- **Initial V2Suit Module Design**
  - Flywheel orientation and placement
  - Integration and packaging
- **Technology R&D**
  - Alternate uses
  - Key technologies

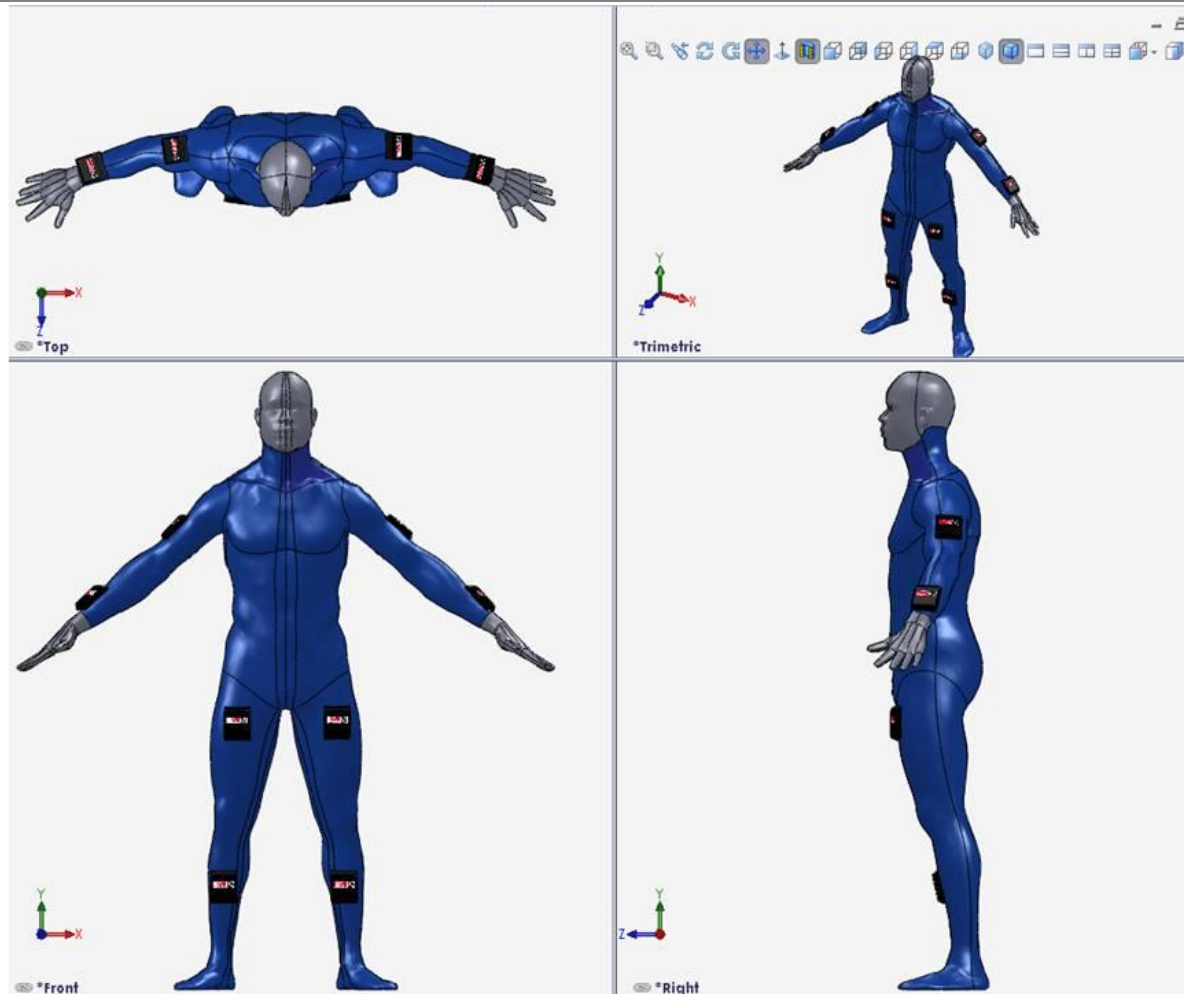




## Human-System Integration



# CAD Modeling



Placement of a V2Suit module on each arm and leg segment

# Upper-Body Integration

Lifesize Mannequin

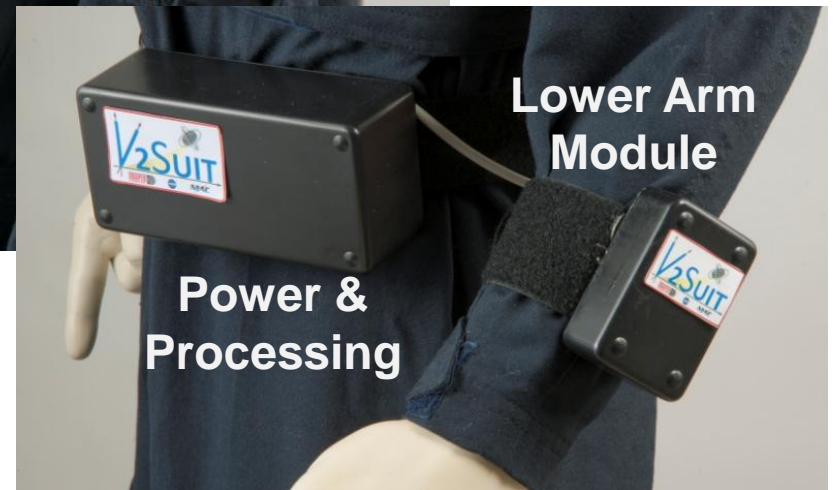


Upper Arm Module



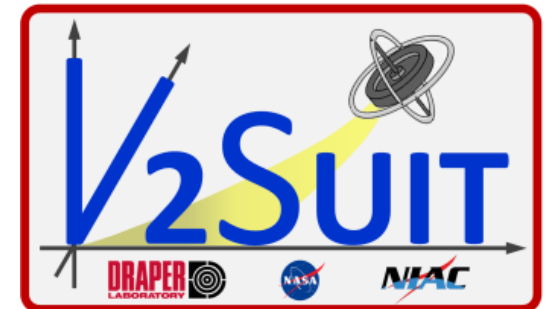
Lower Arm Module

Power & Processing



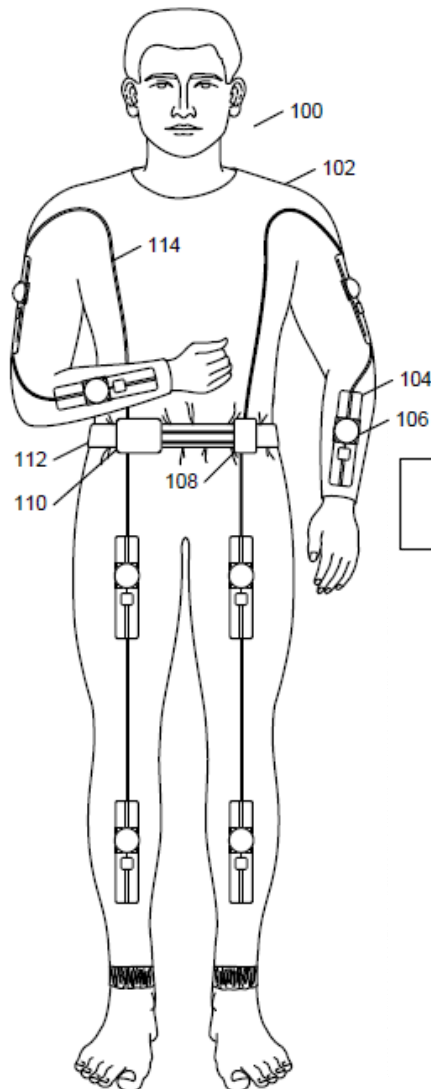


## V2Suit System Architecture & Design



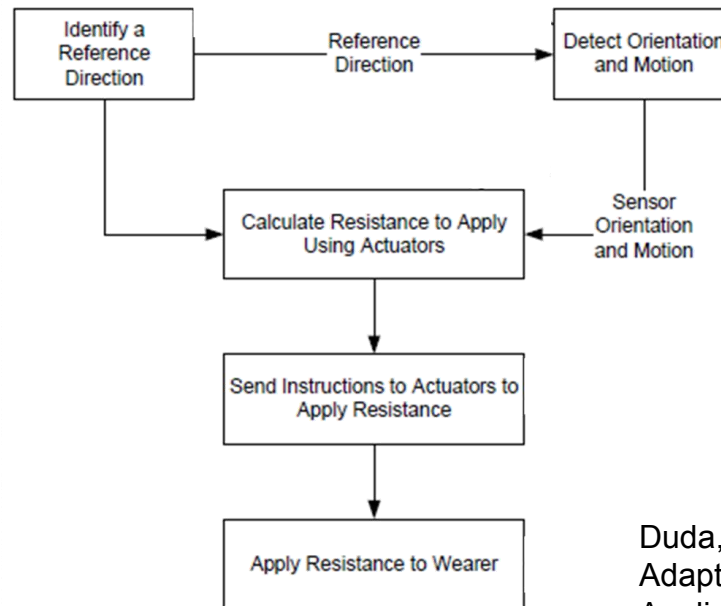


# V2Suit for Space Habitation and Exploration



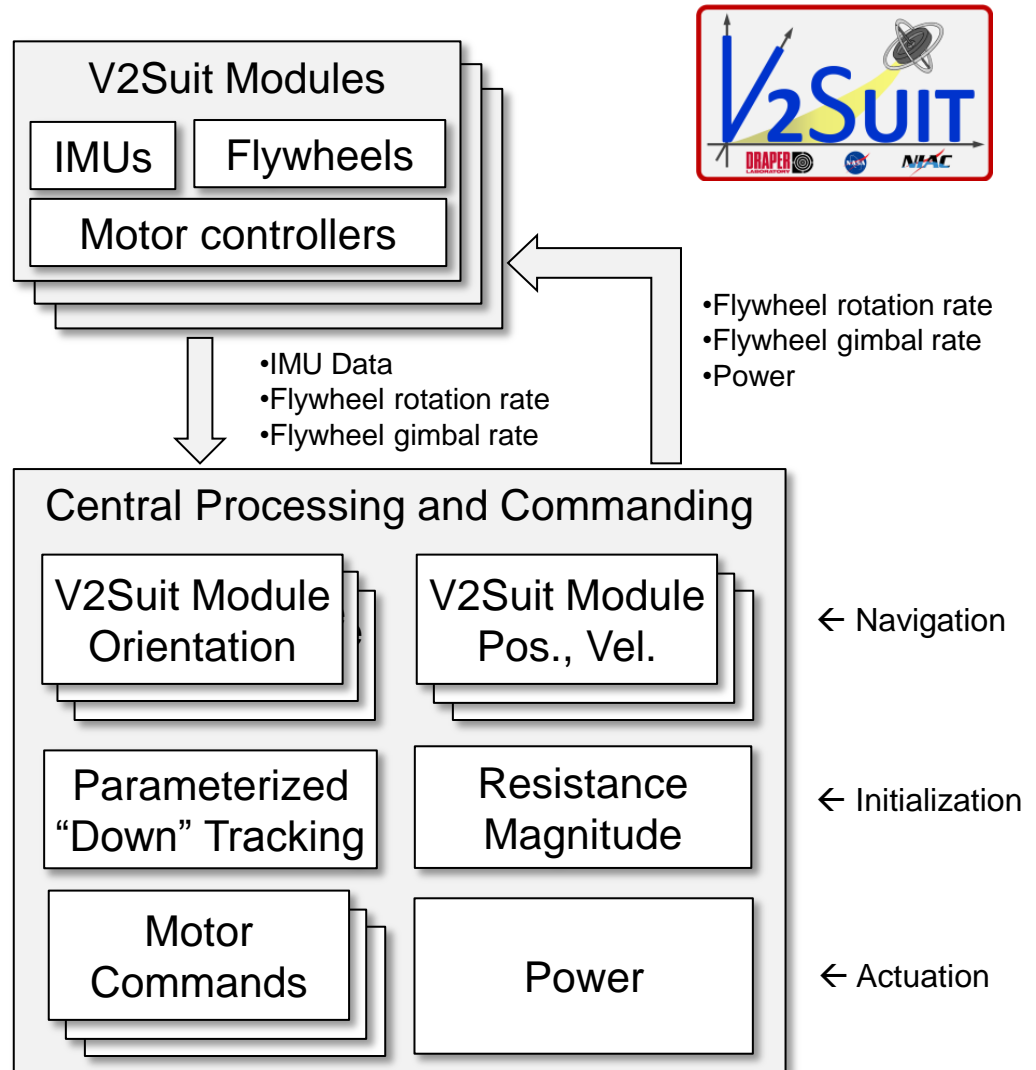
- **V2Suit System**

- Low-profile, wearable system
- Network of sensors and actuators
- Central power and processing



Duda, Zimpfer, Tuohy, West "Exoskeleton Suit for Adaptive Resistance to Movement" U.S. Patent Application submitted 11/30/2011

# V2Suit System Architecture

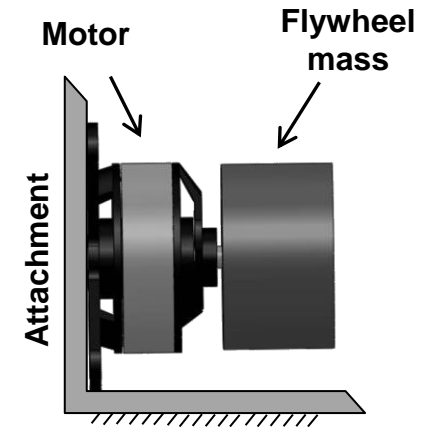


# Generating Gyroscopic Torque

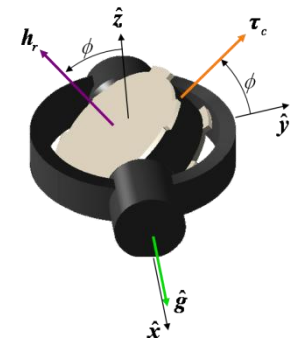
- **Alternatives for a body-worn system**
- **Single Axis Flywheel**
  - Change in flywheel spin rate
  - Change orientation via body kinematics
- **Control Moment Gyroscope (CMG)**
  - Variations in: spin rate, gimbal rate
  - Command torque direction and magnitude
  - Adds complexity
    - Slip rings & bearings

Multiple 2-axis CMGs have ability to provide desired torque direction and magnitude within a body-worn form factor

## Single Axis Motor & Flywheel



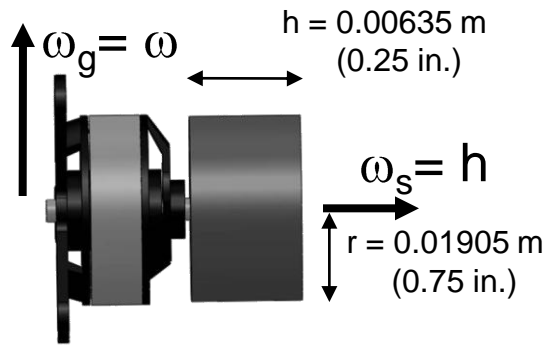
## Control Moment Gyroscope



M. Peck lecture on CMGs, Cornell Univ.

$$\vec{\tau} = -\vec{\omega} \times \vec{h}$$

# Gyroscopic Torque Parameters



## Material:

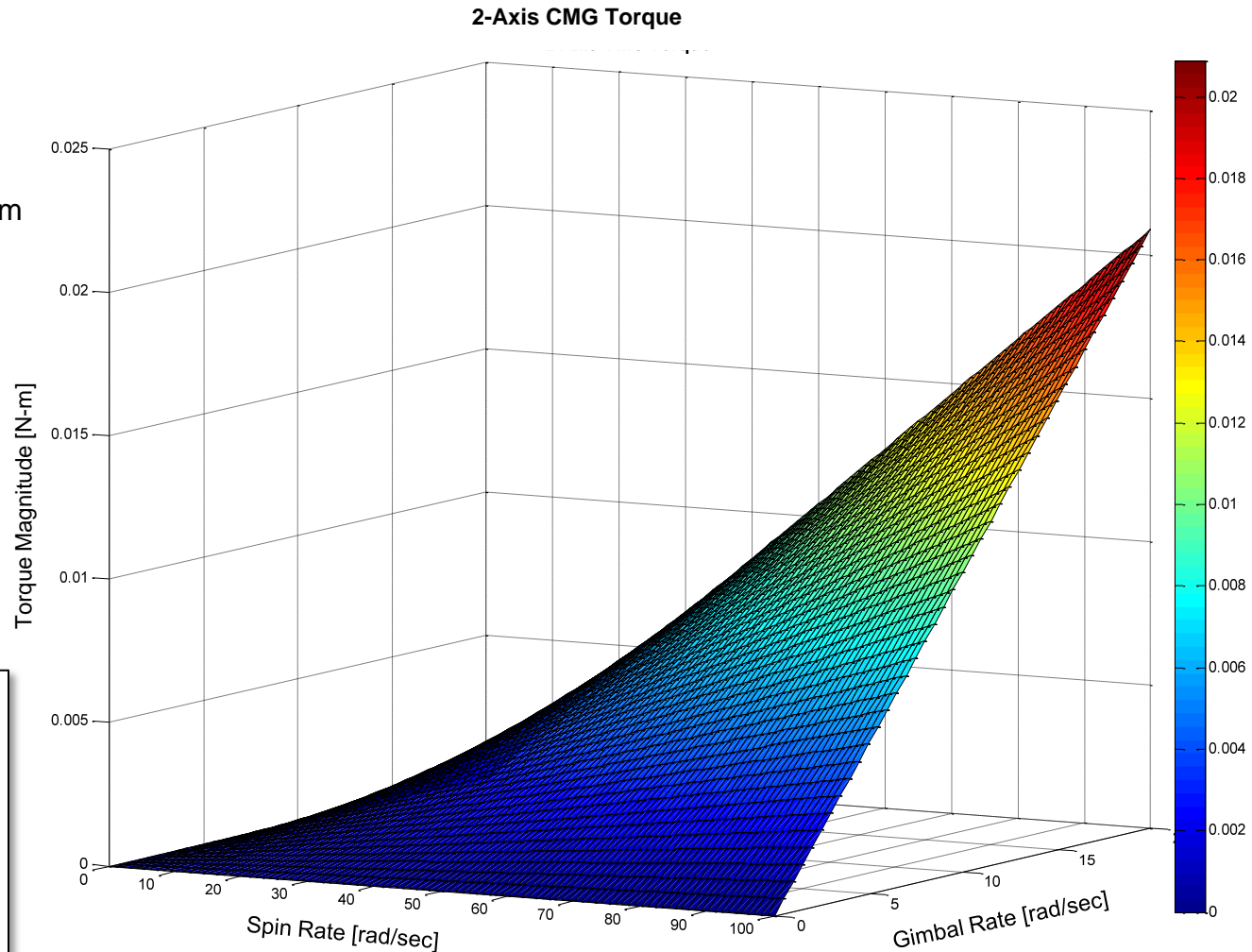
Stainless steel,  
 $\rho = 7950 \text{ kg/m}^3$   
 $m = 0.0576 \text{ kg}$

$$I_x = 1.0443 \cdot 10^{-5} \text{ kg} \cdot \text{m}^2$$

## Variables:

- *moment of inertia*
- *spin rate*
- *gimbal rate*

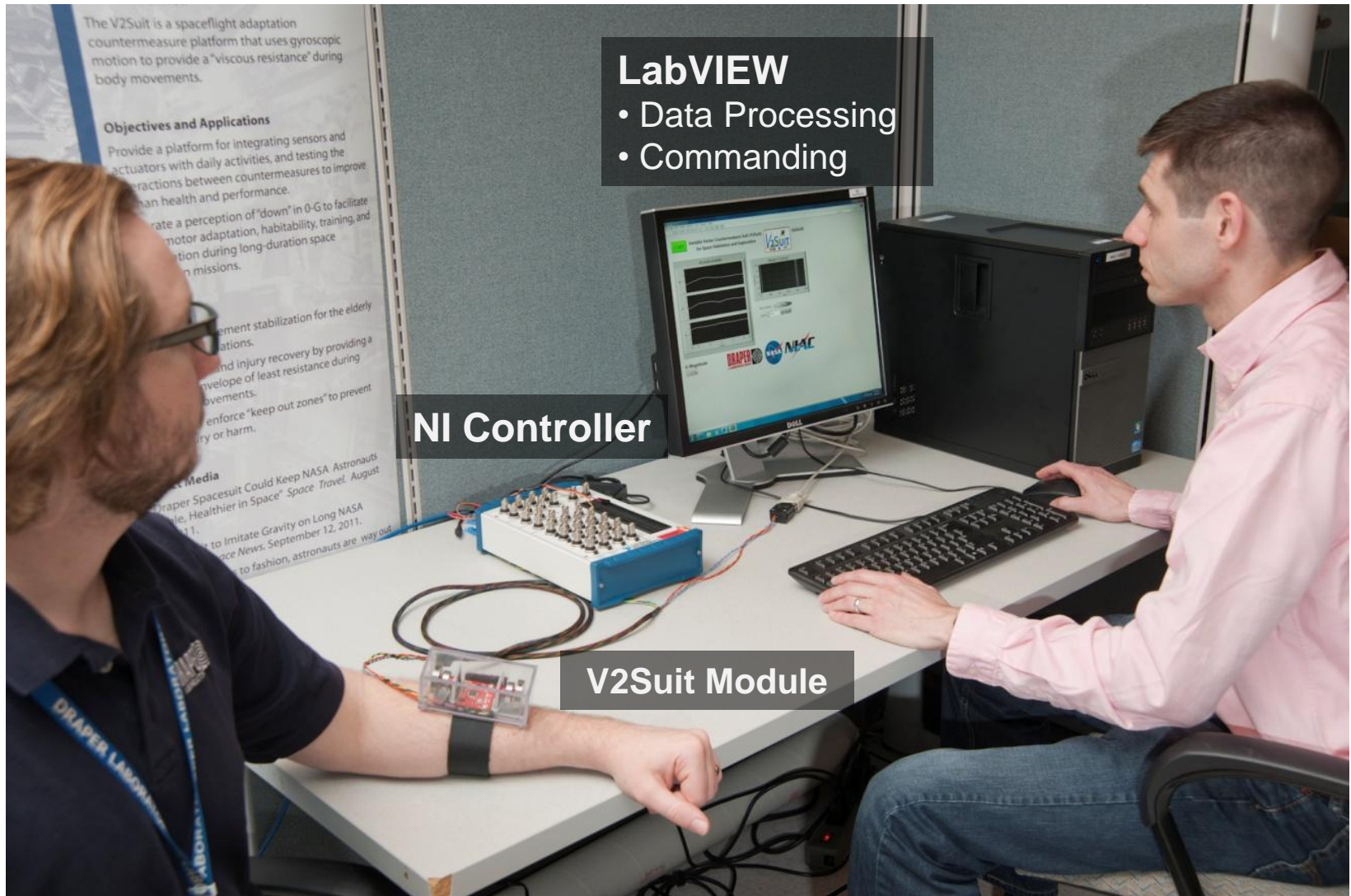
to generate the desired torque



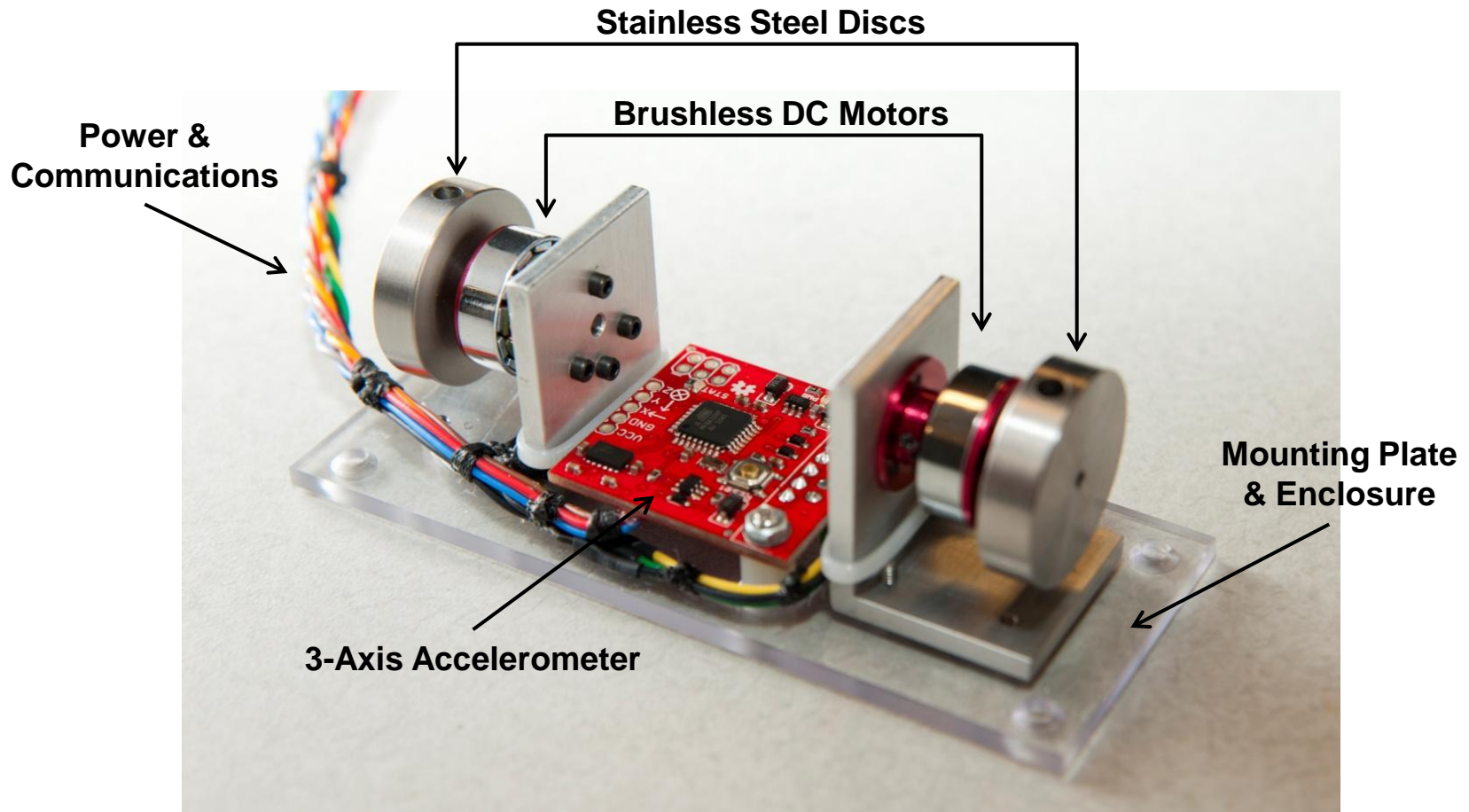
100 rad/sec = 954 rpm



# Benchtop Concept Demonstration



# V2Suit Module Prototype



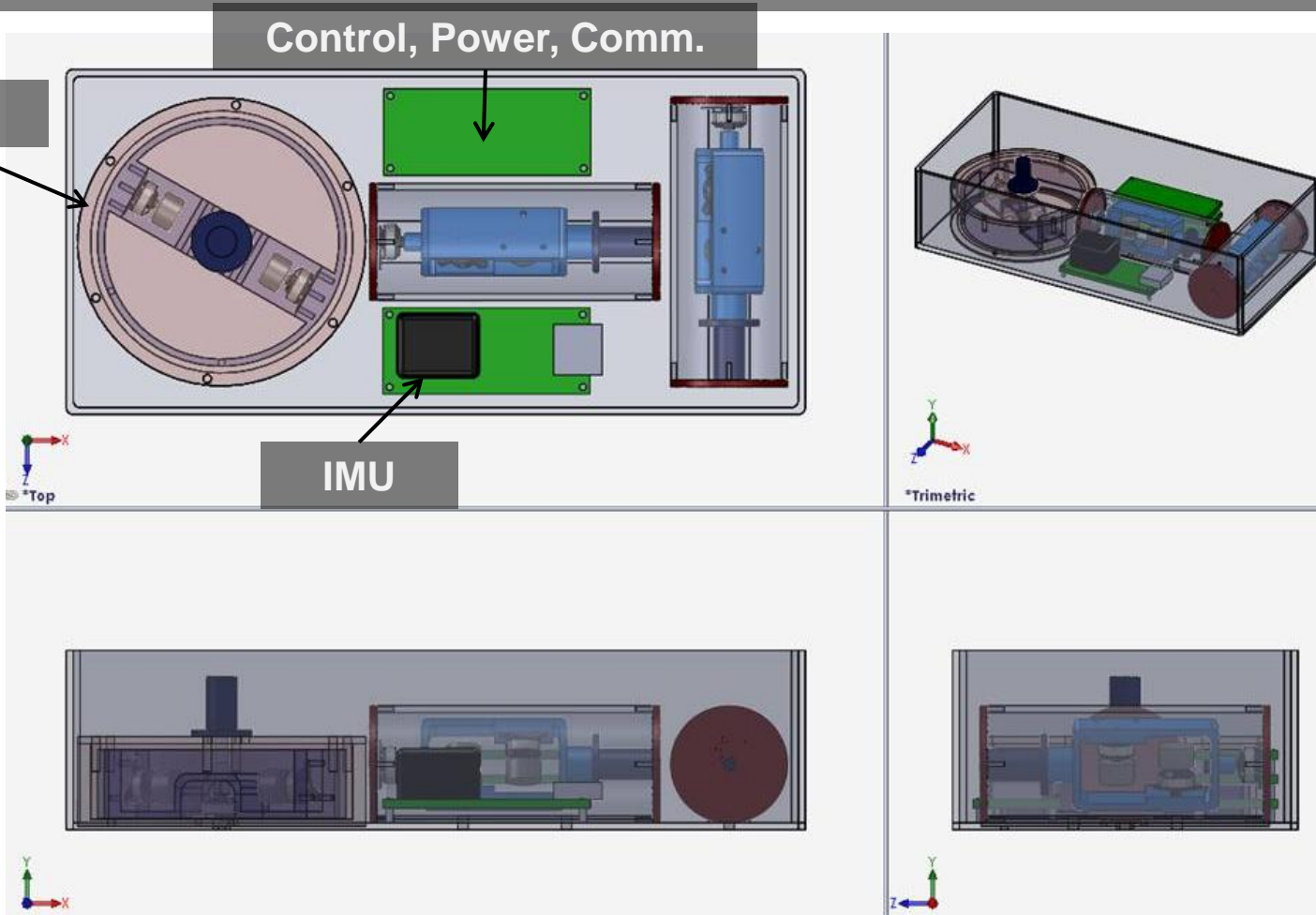
Prototype built from RC aircraft/helicopter components to demonstrate concept and develop technology roadmap

# V2Suit Module Packaged Concept

Control, Power, Comm.

CMG

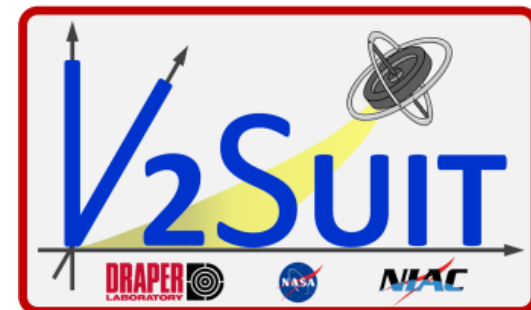
IMU



Multiple control moment gyroscopes packaged with on-board IMU, motor controller, and power/communications interface



## Technology R&D

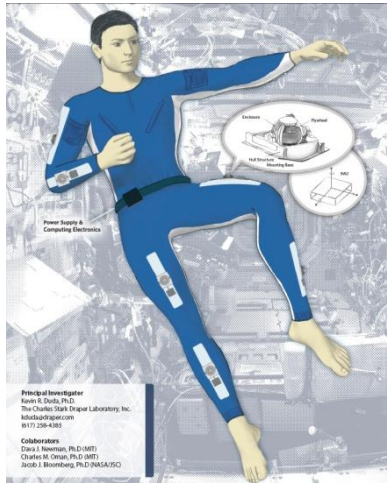




# V2Suit Alternate Uses

- **Spacecraft Interior**

- Sensorimotor
- Musculoskeletal



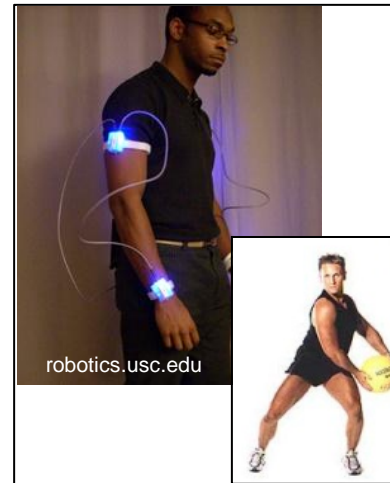
- **Low-G EVA**

- Stabilization
- Orientation control



- **Exercise/Rehabilitation**

- Movement trajectories
- Posture stabilization



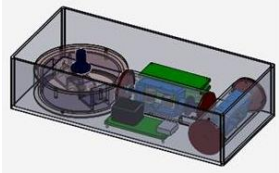



- **Industrial**

- Keep-out zones
- Safety zones



*Platform Technology for Space- and Earth-based Applications*

# Key System Components

System Attribute	Current State	Tech R&D
<b>Packaging</b> <ul style="list-style-type: none"> <li>• Spin and gimbal motors</li> <li>• Slip rings, bearings</li> <li>• IMU</li> <li>• Motor controllers, comm.</li> </ul>	<ul style="list-style-type: none"> <li>▪ ~36 in3</li> <li>▪ COTS                             <ul style="list-style-type: none"> <li>• Spin motors</li> <li>• Motor controllers</li> </ul> </li> <li>▪ MEMS IMUs</li> </ul> 	<ul style="list-style-type: none"> <li>▪ Micro motors</li> <li>▪ Slip rings</li> <li>▪ Vibration</li> </ul>
<b>Navigation</b> <ul style="list-style-type: none"> <li>• Position/Orientation Initialization</li> <li>• “Down” Tracking</li> </ul>	<ul style="list-style-type: none"> <li>▪ Kalman filter</li> </ul> 	<ul style="list-style-type: none"> <li>▪ Body worn relative motion</li> <li>▪ Initialization</li> <li>▪ Temporal drift</li> </ul>
<b>Control</b> <ul style="list-style-type: none"> <li>• Response time</li> <li>• Spin vs. gimbal rate</li> </ul>	<ul style="list-style-type: none"> <li>▪ &gt; 1000 rpm spin rate</li> <li>▪ No gimbal motor</li> <li>▪ ~50 ms response delay</li> </ul> 	<ul style="list-style-type: none"> <li>▪ Spin/gimbal coordination, respond to whole body movement</li> </ul>
<b>Power</b> <ul style="list-style-type: none"> <li>• Steady state vs. transient</li> <li>• Operations duration</li> </ul>	<ul style="list-style-type: none"> <li>▪ 2 W steady state, 12 W spike (COTS components)</li> </ul>	<ul style="list-style-type: none"> <li>▪ Motor selection</li> <li>▪ Custom controllers</li> <li>▪ Battery sizing</li> </ul>
<b>Human-System Integration</b> <ul style="list-style-type: none"> <li>• Wearability</li> <li>• Resistance magnitude</li> <li>• Perceptual artifacts</li> </ul>	<ul style="list-style-type: none"> <li>▪ Outer garment</li> <li>▪ Central power/cmd</li> </ul> 	<ul style="list-style-type: none"> <li>▪ Don/doff time</li> <li>▪ Garment integration</li> <li>▪ Perceptual experiments</li> </ul>

*Identify and assess risks with key system technologies through early-stage evaluations, prototypes and simulations*

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  - Integration and packaging
- **Technology R&D**
  - Alternate uses: earth and space
  - Key technologies for future R&D

